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SOURCE ATTRIBUTION OF PM FOR BERLIN USING LOTOS-EUROS

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Abstract:
Air Quality in Berlin is a problem especially during winter episodes. During such episodes the build-up of pollutants released within the city is just one factor contributing to the high concentrations. During conditions with easterly winds and inversion situations with low planetary boundary layer heights pollutants produced in Eastern Europe are adverted to Berlin. To support the development of the air quality plan for Berlin the origin of the pollution for the annual mean and during episodes is required. To be able to attribute the share of the overall pollution in Berlin for 2014-2017 to its origins the labelling approach incorporated in the Chemistry Transport Model (CTM) LOTOS-EUROS v2.1 is used. During winter episodes agriculture and residential combustion are the most important sectors, each contributing about 30% to PM2.5 mass. Secondary contributions come from industry, energy production and traffic. The latter is the most important local source. Only during the highest episodes the Polish contribution to PM2.5 exceeds that of Germany, whereas the Polish contributions are generally as high as the combined contribution of other eastern European countries. During summer 2018 the model system underestimates the PM10 concentrations due to the large fraction of coarse mode material related to the drought conditions.

Key words: *Particulate matter, source apportionment, Berlin*

INTRODUCTION

Particulate Matter affects human health by penetrating deep into the lungs and even into the bloodstream. It is responsible for several lung and heart diseases and exposure to particulate matter is associated with a reduced life expectancy of 6 to 12 months. Authorities therefore devised limit values for Particulate Matter. The exceedances of these thresholds occur mostly in urban agglomerations due to the proximity to sources caused by a range of human activities within the urban area. Air Quality in Berlin is a problem especially during winter episodes. During such episodes the build-up of pollutants released within the city is just one factor contributing to the high concentrations. During conditions with easterly winds and inversion situations with low planetary boundary layer heights pollutants produced in Eastern Europe are adverted to Berlin. To support the development of the air quality plan for Berlin the origin of the pollution for the annual mean and during episodes is required. Below we present the results of a modelling study to quantify the source sectors and regions to particulate matter in Berlin.

METHODOLOGY

LOTOS-EUROS

In this study we use the LOTOS-EUROS 3D chemistry transport model (Manders et al., 2017). As a part of the Copernicus Atmospheric Monitoring (CAMS) regional ensemble it provides operational forecasts and analysis for Europe (Marecal et al., 2015). In this study we use the source apportionment routines of LOTOS-EUROS which allows to trace the contributions of pre-defined source sectors to all PM components (Kranenburg et al., 2013).

Model set-up

The model was set up for a 3-year simulation (2016-2018), where the first two years were simulated without labelling, while the third year was simulated with the labelling approach.
The meteorological input comes from the ECMWF (European Centre for Medium-range Weather Forecasts). For the emissions there are different datasets: for Germany the GRETA (Gridding Emission Tool for ArcGIS) inventory was used, whereas for the rest of Europe the CAMS regional inventory developed by TNO for 2015 was used. For the temporal variation by accompanying monthly, daily and hourly time factors that are derived from the annual values.
In this study the primary particulate matter, including EC-OC, for Residential Wood Combustion (RWC) are exchanged regarding to the national reporting in the GRETA and CAMS regional inventories by a scientific bottom-up inventory for Europe. The thus obtained inventory for RWC contains a consistent set of emission factors for wood combustion and also the impact of condensable material (Denier Van Der Gon et al., 2015). For residential fossil fuel combustion there is a specification which follows the emission factors from GAINS model. As the primary fine particulate matter anthropogenic emissions have increased from 1345 to 2286 kiloton in the EU28, the RWC emissions within this study are significantly higher than the officially reported by a factor of 2-3. To reproduce a realistic variability in the emissions the temporal variability of RWC was calculated by heating degree days.
The model simulations were ran for a European domain (D1) and a nested Germany-Poland domain (D2). The D1 simulation has a resolution of 25 km and the D2 simulation a resolution of 7 km.
The labels used in this work are based on the thought to get more detailed information on the originating regions, especially the states surrounding Berlin and the neighbouring countries. By also labelling the source sectors for the individual regions (except other) it is possible to also specify the originating sector. In this study we labelled four important sectors and all others for each of the regions specified in Table 1.

Table 1. Overview of the used labels for countries and sectors

Labelled countries	Labelled sectors
Berlin	Traffic
Brandenburg	Households
Rest of Germany	Industry/Energy
Poland	Agriculture
Czech Republic	Rest
Others	
Natural	
Boundary	

Observations

In this study we used the observations from the Berlin Air Quality Network (Blume) (ref) supported by rural stations from the state of Brandenburg. For this work the Berlin contribution to the within Berlin measured concentrations is essential. Thus we selected four stations representing the three urban and the rural locations: BEFRA (DEBE065)[1] as an urban traffic station, BENAN (DEBE034) as an urban background station, BEHOB (DEBE051) as a suburban station and BBNEU (DEUB030) as a rural station. In Figure 1 we illustrate the PM concentration gradient measured at these stations through the so-called Lenshow approach. Note that the annual mean concentration measured at the urban traffic station is about two times higher than the regional background value.

[1] DEBE065 is the UBA (Umweltbundesamt) code for the station (see: www.umweltbundesamt.de).

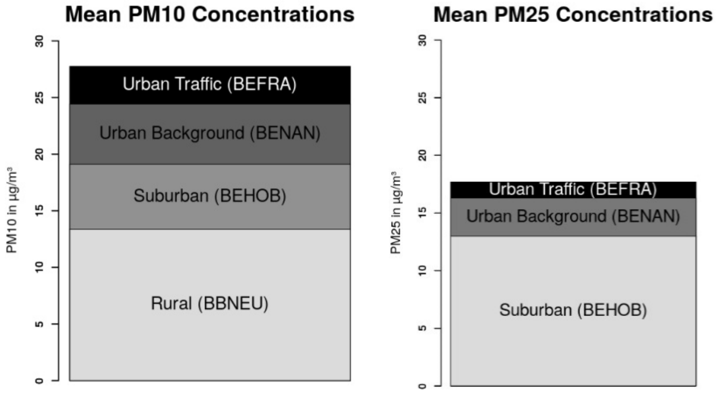

Figure 1. Example of the PM10 (Left) and PM2.5 (Right) concentration gradients observed for Berlin for 2018.

RESULTS

Model performance

To assess the robustness of the model to simulate PM10 and PM2.5 concentrations, we evaluated the model against observations for a Berlin urban background station (BENAN shown here). The simulated annual average PM10 concentrations for 2018 are in the range of 12 to 14 µg/m³ while for the observations these are about 16 to 25 µg/m³. While for PM2.5 the simulations show values between 8 and 10 µg/m³ and the observations values in the range of 13 to 16 µg/m³. The daily values for simulated against observed PM10 and PM2.5 concentrations for BENAN are shown in Figure 2. Where for PM10 the simulation underestimates the observed concentrations especially for high concentrations, the simulated PM2.5 concentrations are much better caught by the model. Also for higher concentrations the model is able to reproduce increased concentrations even though the full amplitude is not reproduced. All in all the simulated PM2.5 concentrations are closer to the 1:1 line than PM10.

When looking at the observational data for PM10 and PM2.5 for the Berlin background station BENAN there is an obvious change in the contribution of PM2.5 to the overall PM10 mass. During the January-March winter season the contribution is quite large (80% or in absolute values 21 µg/m³ PM2.5 in comparison to 26 µg/m³ PM10), while during summer (May-September) it is considerably lower (52%, in absolute values 12 µg/m³ PM2.5 in comparison to 23 µg/m³ PM10). The increased level of coarse material is probably mostly due to resuspension of dust by traffic and agriculture occurring inside and outside the city and was amplified during 2018 due to the severe drought conditions in Central Europe. Unfortunately, the model does not incorporate a dust resuspension scheme leading to a significant underestimation of the coarse mode material during summer. As a consequence, we focus on the source apportionment results for PM2.5 below.

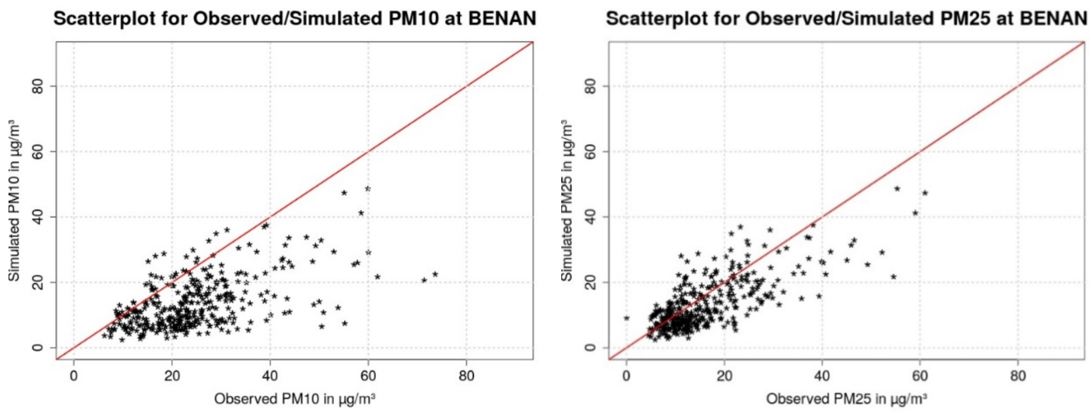

Figure 2. Scatterplots for the PM10 and PM2.5 concentrations for simulation against observations for gridpoint BENAN (daily values).

Source attribution

Region

In figure 3 (upper panel) we provide the modelled origin of PM2.5 with respect to region of origin. The total bars represent the observed concentration, whereas the modelled source apportionment is coloured in. For the first three month of 2018 the figure shows that the model reproduces the variability in the observations, albeit with a variable underestimation. The mode results indicate that the origin of the individual episodes differ. For instance, the episode in February shows large Berlin and national contributions, whereas the one in March shows a large polish contribution. The contribution of the state of Brandenburg is minor throughout the timeseries. Only during the highest episodes the Polish contribution to PM2.5 exceeds that of Germany, whereas the Polish contributions are generally as high as the combined contribution of other eastern European countries.

The green bar indicates the Berlin contribution, which is highest during episodes. For example, the episode around the 10^{th} of February was characterized by low temperatures (below 0°C), no precipitation and calm wind conditions. This caused an accumulation of PM and other pollutants by reduced dilution of pollutants and the inhibited dry deposition, while the emissions of heating were increased explaining the enhanced local contribution to PM.

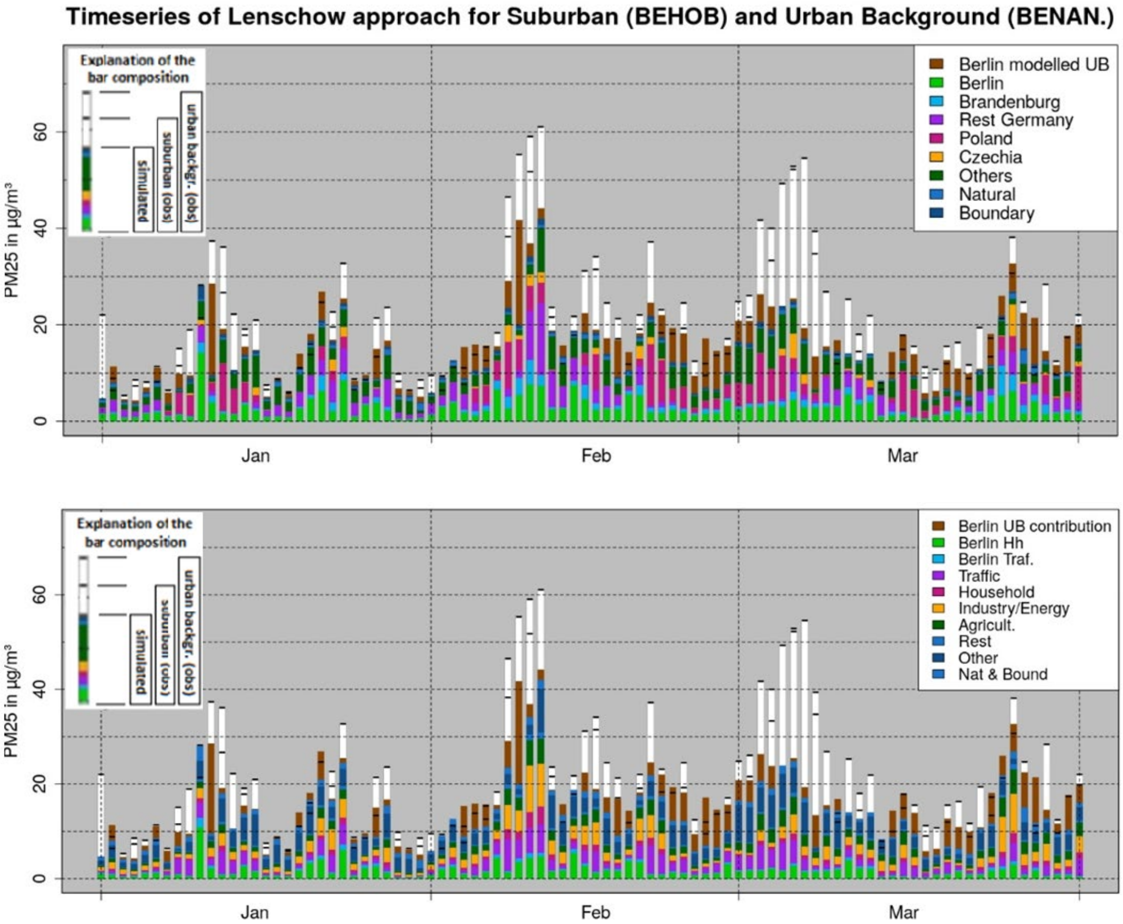

Figure 3. Time series for PM2.5 for observational and simulated data for BENAN for January to March, 2018. The suburban concentration level for BEHOB is also indicated. For the country wise labelled concentrations (top) and for the sector wise labelled concentrations (bottom) the daily mean concentrations can be directly compared to the shown observations (white bars in both plots).

Sector

Generally, residential combustion and agriculture are the most important sectors during wintertime, each contributing up to about 30% to PM2.5 mass. Secondary contributions come from industry, energy production and traffic. Households and traffic are the most important local sources.

As for the regional results, the sector apportionment varies from day to day. When looking closer to the high concentration episodes in February the major contribution comes from Berlin Households, Traffic and Industry/Energy and for one day the Berlin urban background contributes to the half of the simulated concentrations. As said before this days were dominated by calm weather. This contribution of the sectors to the overall concentrations during high concentration episodes can also be seen for the winter season (November-December) 2018.

Note that due to the specific labelling definition the contribution of “other” is in both graphs the same as the sector of origin and was not traced. Early March the model predicts a relatively large fraction of other, in this case meaning other countries east of Poland and Czech Republic.

CONCLUSIONS

We have successfully applied the LOTOS-EUROS model to investigate the origin of PM episodes in Berlin during 2018. During winter episodes agriculture and residential combustion are the most important sectors, each contributing about 30% to PM2.5 mass. Secondary contributions come from industry, energy production and traffic. The latter is the most important local source. Only during the highest episodes the Polish contribution to PM2.5 exceeds that of Germany, whereas the Polish contributions are generally as high as the combined contribution of other eastern European countries. During summer 2018 the model system underestimates the PM10 concentrations due to the large fraction of coarse mode material related resuspension of dust, most likely increased due to the drought conditions in 2018.

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